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GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION

PROJECT INITIATION

Date: April 3, 1975

Project Title: Design Analysis for Implementation of Polarization Agility With Target Recognition

Project No.: A-1723

Project Director: Mr. J. L. Eaves

Sponsor: U. S. Army Missile Command; Redstone Arsenal, Ala. 35809

Agreement Period: From March 13, 1975 Until Sept. 30, 1975 (Contr. Term)

Type Agreement: Contract No. DAAH01-75-C-0639

Amount: $15,000

Reports Required: Monthly Progress Letters; Final Technical Report

Sponsor Contact Person:

Technical Matters
Chief, Advanced Sensors Directorate
U.S. Army Missile R,D & E Laboratory
U. S. Army Missile Command
Attn: AMSMI-RER
Redstone Arsenal, Ala. 35809

Contractual Matters
(Thru GTRI)
Mr. R. J. Whitcomb (ACO)
ONR RR - Ga. Tech - Campus

Defense Priority Rating: DO-A2 under DMS Reg. 1

Assigned to: RADAR

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RA-3 (3-75)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

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Date: September 29, 1976

Project Title: Design Analysis for Implementation of Polarization Agility With Target Recognition

Project No: A-1723

Project Director: Mr. J. L. Eaves

Sponsor: U. S. Army Missile Command; Redstone Arsenal, AL 35809

Effective Termination Date: 9/12/75 (Contract Expired)

Clearance of Accounting Charges: 9/30/75

Grant/Contract Closeout Actions Remaining:

- _ Final Invoice and Closing Documents
- _ Final Fiscal Report
- x Final Report of Inventions
- x Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ______________

Assigned to: Applied Engineering Laboratory (School/Laboratory)

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CA–4 (3/76)

A-1723

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

9 May 1975

U.S. Army Missile Command
Advanced Sensors Directorate
RF Guidance Section
Redstone Arsenal Alabama 35809

Attention: A. H. Green, Jr.

Subject: Research and Development Contract Status Report No. 1
"Design Analysis for Implementation of Polarization Agility with Target Recognition"
Contract No. DAAH01-75-C-0639
Covering Period 7 March 1975 through 30 April 1975

Gentlemen:

The subject contract became effective on 7 March 1975. The research program will be conducted within the Radar Division of the Engineering Experiment Station and has been assigned as Georgia Tech Project A-1723.

Activities during this period have included a review of available material related to the application of polarization agility to the breadboard target recognizer. Based on the review and on results of technical meetings at MICOM and at Bendix, Georgia Tech does not foresee any insurmountable technical difficulties associated with modifying the breadboard target recognizer system for polarization agility. It is Georgia Tech's understanding that the modified breadboard target recognizer will utilize two antennas, the original antenna for transmission and a second antenna for reception. The feed for the original antenna will be reoriented such that either horizontal or vertical polarization can be selected for transmission. The second antenna, or receiving antenna, will employ a dual-polarized feed and a ferrite switch such that horizontal or vertical polarization on reception can be selected on a pulse-to-pulse basis. Also reception on an alternate pulse basis of plus and minus 45 degrees linear polarization will be possible by mechanically rotating the feed system. Other changes to the breadboard target recognizer will be in the area of paper-tape unit operation and format. That unit will be modified to handle the additional polarization by utilizing data from every eighth transmission as opposed to every sixteenth transmission in the original configuration.

Visits

Mr. J. L. Eaves and Mr. J. M. Schuchardt of Georgia Tech visited the U.S. Army Missile Command on 14 April 1975 for the purpose of discussing tasks and priorities for the subject program. Army personnel participating in the discussion included Mr. A. H. Green, Mr. C. Callaway and Mr. Bob Haraway.

On 22 April 1975, Mr. J. M. Schuchardt of Georgia Tech visited Bendix in Baltimore, Maryland, for the purpose of reviewing proposed plans for modifying the breadboard target recognizer for polarization agility operation. Mr. Coleman Callaway of MICOM also visited Bendix on that date. It is Georgia Tech's conclusion that the modifications proposed by Bendix are straightforward and no insurmountable technical difficulties should be encountered.

Future Efforts

During the next period activities under the subject contract will proceed according to the plan and schedule included in Georgia Tech's proposal and the technical requirement included in the contract document. Georgia Tech will keep MICOM personnel informed of major activities performed under the program via telephone reports on a week-to-week basis.

Respectfully submitted,

J. L. Eaves
Project Director

Approved:

H. Allen Ecker
Chief, Radar Division

A-1723

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

17 June 1975

U.S. Army Missile Command
Advanced Sensors Directorate
RF Guidance Section
Redstone Arsenal, Alabama 35809

Attention: A. H. Green, Jr.

Subject: Research and Development Contract Status Report No. 2
"Design Analysis for Implementation of Polarization Agility with Target Recognition"
Contract No. DAAH01-75-C-0639
Covering Period 1 May 1975 through 31 May 1975

Gentlemen:

Technical Progress

During this period activities under the subject contract were concentrated in the following areas:

1. The identification and listing of candidate techniques for generating short RF pulses for use in target recognition radar systems.

2. A survey and listing of available short pulse power sources and suppliers, including approximate cost and procurement time.

3. A study and analysis directed toward identification of the best compromise pulse length for use in target recognition systems.

Efforts were directed in the areas listed above as a result of a technical conference on 8 May 1975 and subsequent telephone conversations with the project engineer at MICOM. A partial listing of techniques for generating short pulse waveforms considered thus far include the following:

- o Pre-excited Pulsing - It is anticipated that pulse lengths ranging from 20 nsec to 30 nsec can be achieved with rise times on the order of a few nanoseconds.

- o Parallel Configuration of Low Power Short Pulse Sources.

- o Pseudo Short Pulse through the Use of Polarization Techniques.

- o Summation and Cancellation of Parallel Paths through the Use of Microwave Plumbing.
- o Short Pulse Magnetron Sources - Space microlab looks promising.
- o Swept RF Frequency in Combination with a Bandpass Filter.
- o Pseudo Short Pulse Using Pulse Compression Techniques.
- o Waveguide Transit Time Modulator.
- o Spike Leakage - Ferrite or TR tube.

All of the techniques listed above appear to have the potential for generation for short pulses. However, not all have been thoroughly investigated and may prove to be impractical upon further consideration. Other more speculative techniques were identified but are not included in this listing.

In addition to the activities described above, numerous vendors of microwave power sources were contacted about the possibility of generating short radar pulses with relatively high peak power in the frequency region from X-band through K_a-band. All of the data from the various potential vendors has not been received as of the end of this reporting period. Therefore, those data will be presented in a subsequent report. At this point, Georgia Tech is confident that pulse lengths in the range from 5 to 20 nsec with sufficient power for radar application can be generated.

In addition to the identification of candidate techniques for generating short pulses and the survey of suppliers of short pulse power sources, Georgia Tech has begun a study and analysis with the objective of determining the best compromise pulse length for use in target recognition systems. Efforts in this area have led to the identification of several possible disadvantages of employing very short radar pulse lengths. Some of the potential disadvantages are as follows:

- o An extremely stable time base is required or else time jitter of the short pulse may preclude pulse-to-pulse target-to-clutter discrimination techniques as well as long-term averaging normally obtained by video pulse integration.
- o Effects of multipath propagation become more obvious as the pulse length is shortened.
- o For a fixed PRF system peak pulse power must be increased as pulse length is shortened in order to maintain a given average power.
- o As the receiver bandwidth is increased to accommodate a shorter pulse, the receiver noise also increases, thus signal-to-noise ratio is decreased.

There are numerous advantages in the utilization of short pulse techniques in a target recognition system and these will be discussed in a subsequent report. The current study indicates that rise and fall times in the modulation of an RF pulse may be as important as pulse length in a target recognition system. These considerations also will be discussed further in a subsequent report.

Visits

On 8 May 1975, Mr. Jerry Eaves, Mr. Glenn Riley, and Mr. Bob Appling of Georgia Tech visited MICOM. The general purpose of the visit to MICOM was to discuss an outstanding Georgia Tech proposal to MICOM and, therefore, costs incurred as a result of the visit to MICOM were not charged to the subject contract. However, Georgia Tech and MICOM personnel took advantage of the opportunity to discuss technical aspects of the subject contract. MICOM personnel participating in the discussions included the project engineer, Mr. Hammond Green, Mr. Ralph Nelson, Mr. Coleman Callaway, and Mr. Jim Mullins. It was agreed that Georgia Tech participation in the polarization modification to the 35 GHz breadboard radar and target recognition system could and should be minimal. Therefore, activities under the current contract could and should be redirected to supply information for use in a subsequent program to develop and evaluate a frequency agile targeting system. It was agreed that the following list of considerations would be addressed pending review and approval by MICOM management personnel.

1. Study, analyze and recommend preliminary approaches for achieving short pulse lengths based upon performance tradeoff and cost assessment of various candidate techniques.

2. Survey and determine state-of-the-art for achieving very short (1 - 5 nsec) pulse lengths.

3. Based on available components and other considerations, determine and recommend a frequency band of operating.

4. Initiate efforts to design a transmitter system including short pulse capability if feasible for use in a frequency agile targeting system.

5. If multiple transmitter approach appeared desirable, study and determine requirements of dual transmitter and signal processor multiplexing, control logic, etc.

Future Efforts

During the next period efforts will be continued in the three areas listed at the beginning of this report.

Respectfully submitted,

J. L. Eaves
Project Director

Approved:

H. A. Ecker
Chief, Radar Division

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

9 July 1975

U.S. Army Missile Command
Advanced Sensors Directorate
RF Guidance Section
Redstone Arsenal, Alabama 35809

Attention: A. H. Green, Jr.

Subject: Research and Development Contract Status Report No. 3
"Design Analysis for Implementation of Polarization Agility with Target Recognition"
Contract No. DAAH01-75-C-0639
Covering Period 1 June 1975 through 30 June 1975

Gentlemen:

During this period a new radar concept, referred to as Intrapulse Polarization Agile Radar (IPAR) was conceived under efforts unrelated to this contract. It is mentioned herein because of its potential application to this and other MICOM programs. A description of the concept is provided in the form of a concept disclosure as an attachment to Georgia Tech Proposal No. ST-RD-75-054, "Change-in-Scope of Contract DAAH01-75-C-0639," dated 30 June 1975.

Technical Progress

A partial listing of techniques for generating short pulse waveforms was provided in status report No. 2. That list with additions is provided again for convenience.

Short Pulse Waveform Generation Techniques

- Pre-excited Pulsing - It is anticipated that pulse lengths ranging from 20 nsec to 30 nsec can be achieved with rise times on the order of a few nanoseconds.
- Parallel Configuration of Low Power Short Pulse Sources.
- Pseudo Short Pulse through the Use of Polarization Techniques.
- Summation and Cancellation of Parallel Paths through the Use of Microwave Plumbing.
- Short Pulse Magnetron Sources.

- o Swept RF Frequency in Combination with a Bandpass Filter.
- o Pseudo Short Pulse Using Pulse Compression Techniques.
- o Waveguide Transit Time Modulator.
- o Spike Leakage - Ferrite or TR Tube.
- o Amplification of Short Pulse Generated at Low Power with Wide Band Amplifier.

The most obvious approach for generation of short pulses is to find a capable transmitting device. Sources for transmitting devices capable of pulsewidths approaching 30 ns are available but none have been located for pulsewidths of 10 - 15 ns. The next most favored approach for generating short pulses is to create the short pulse at low power and to achieve the desired power level through the use of a wideband amplifier.

The latter approach is confirmed as a valid one through the existence of working hardware which generates pulses which are less than 1 ns, at the power levels of interest.

A technical memorandum discussing short pulse considerations has been completed and will be forwarded.

Visits

On Thursday, 19 June 1975, Jerry Eaves and Bob Appling visited with Carl Cash and Hammond Green of MICOM. During the visit the results of the short pulse analysis were discussed. MICOM personnel were also presented with a blackboard description of the IPAR concept.

Future Efforts

During the next period efforts will continue in the short pulse analysis, potential problems, and special considerations. Since the means of generating such pulses τ 1/ns has been defined and confirmed by the existence of hardware, no further effort will be expended in defining short pulse techniques or short pulse device sources.

Respectfully submitted,

B. C. Appling
For J. L. Eaves,
Project Director

Approved:

H. A. Ecker
Chief, Radar Division

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

15 August 1975

U.S. Army Missile Command
Advanced Sensors Directorate
RF Guidance Section
Redstone Arsenal, Alabama 35809

Attention: A. H. Green, Jr.

Subject: Research and Development Contract Status Report No. 4
"Design Analysis for Implementation of Polarization
Agility with Target Recognition"
Contract No. DAAH01-75-C-0639
Covering Period 1 July 1975 through 31 July 1975

Gentlemen:

Technical Progress

The following activities and events occurred under the subject contract during this reporting period:

1. An internal Georgia Tech program status review was informally conducted. Details of the status review are included in the attached memorandum dated 10 July 1975. It was concluded that the program had reached a decision point. Georgia Tech's recommendations for program direction have been verbally communicated to program personnel at MICOM and are repeated here.

- The objective of developing a targeting system should continue on the basis of the discrimination and processing techniques expounded in Georgia Tech's Unsolicited Proposal No. ST-RD-75-023, "A Breadboard Frequency Agile Target System (FATS)," dated 7 February 1975. This continuance is recommended regardless of target recognition activity and status.

- An available radar at X-band with a pulse width equal to that specified for target recognition should be utilized. Such utilization would permit early evaluation of recognition techniques, thereby advancing the program schedule and possibly saving money, in the long run.

- The FATS breadboard mentioned above should be developed such that equipment is compatible with recognition requirements. The current program reflects that requirement.

o The Change-in-Scope of Contract DAAH01-75-C-0639, Georgia Tech Proposal No. ST-RD-75-054, dated 26 June 1975, ensures objective observation of recognition-related data gathering, provides for further examination of recognition techniques, and should be accepted.

2. A summary was generated for the Short Pulse Technical Memorandum which analyzes certain short pulse width considerations, discusses certain techniques for generating short pulses, and recommends an optimum pulse width for use with range profile type recognition techniques. The memorandum and summary have been forwarded to MICOM.

3. Preliminary arrangements have been made for MICOM to borrow a short pulse radar for recognition data gathering, analysis, and evaluation.

Future Efforts

Georgia Tech personnel plan to travel to MICOM during the next reporting period for the purpose of briefing MICOM personnel on program status and to observe data collection for target recognition analysis and evaluation. Preparation efforts have commenced on the final report for this contract and will be continued during the next reporting period.

Georgia Tech is prepared to commence work under contract for the FATS and Added Scope proposals. Arrangements will be made for the utilization of a short pulse radar on behalf of MICOM if desired.

Respectfully submitted,

B. C. Appling
For J. L. Eaves,
Project Director

Approved:

H. A. Ecker
Chief, Radar Division

10 July 1975

MEMORANDUM

TO: J. L. Eaves

FROM: B. C. Appling

SUBJECT: Short Pulse Study and Memorandum; Recognition Program

The subject technical memorandum lists several techniques for generating short pulses (~ 10 ns), recommends two approaches, and recommends an optimum pulse width (~ 30 ns). This memorandum does not attempt to analyze the usefulness of range profile recognition techniques. Several potential difficulties are briefly considered, however. It is hoped that such consideration will prove helpful in the specification of design parameters, in the event that a radar development for use with range profile recognition is undertaken.

Proposal ST-RD-75-054 dated 30 June 1975 and forwarded to MICOM reflects the recommendations stimulated by this study. Pulse width is a critical parameter in the recognition concept and should be considered further. Also, a brief survey could show that other recognition techniques provide enhancement or alternatives. Investigation of the IPAR concept could reveal advantages or inadequacies. As a pseudo short pulse technique employing compression and correlation in addition to inherent polarization agility and wide bandwidth, the IPAR concept may have some potential as a target recognition sensor.

So that evaluation of the range profile recognition technique may be accomplished at the earliest time, it is recommended that use of an existing short pulse radar be considered. One has been located and this information has been communicated to MICOM. This radar is available and its operation has been witnessed. The use of this radar would serve several purposes.

- o Provide a sounder basis for the potential short pulse radar development.
- o Add confidence to or reveal serious shortcomings in the recognition concept.
- o Provide desired data for hyperplane modeling.
- o Shorten the time (reduce cost) and increase the probability of program success by permitting a predevelopment evaluation of the recognition technique.

The short pulse study memorandum will most likely have been forwarded to MICOM by the time you read this. The attached PERT type chart and task descriptions reflect a straightforward and logical sequence in which the target recognition program could be approached. Bendix does not appear to have included some of the preliminary or necessary steps in their program plan. Our short pulse study and memo, the change-in-scope proposal, the FATS proposal and tasks outlined therein are in conformance with the attached program plan in that those documents question the lack of analysis and modeling while proposing positive actions toward a remedy for the situation.

TASK DESCRIPTIONS

Specification of Target Characteristics

It is necessary, unless one is depending on intuition and luck, to describe the target's radar scattering characteristics as a prerequisite to target recognition. This can be accomplished to varying degrees but generally the better the target's scattering characteristics are specified, the more successfully it can be distinguished from non-targets and similar targets. There are two basic techniques for specifying these characteristics; the phenomenological and prediction approaches.

The phenomenological approach requires that an accurate model of the target of interest be available. This approach is essentially a process of learning to distinguish between the target and non-targets or similar targets by learning to recognize significant differences. This process has the advantages of reducing the theoretical background analysis which must be accomplished, providing the potential for more accurate recognition, and being more flexible. The major disadvantages are that recognition of a particular target requires an accurate physical model and significant parameters may be overlooked that have potential for distinguishing the target.

The prediction approach requires an accurate theoretical description of target scattering characteristics and care in selecting significant differences. Though not as flexible as the first approach in being reprogrammable for new targets, the prediction approach would have greater versatility in recognizing a well specified target with greater variations in the environment and relative sensor-to-target orientation. Other advantages include the ability to determine significant recognition features without a realistic model and to better decide which parameters offer the best recognition potential. The amount of analysis required is a decided disadvantage.

It is possible that optimum approaches including both of the two basic approaches could be used with the result that the advantages of each could be realized. On the other hand, carelessness could result in the disadvantages of both being realized. The amount of real-time processing required (a realistic hardware consideration) could be considered an advantage or disadvantage of either approach, dependent on the size of the class of targets to be recognized. If only one target need be recognized, the phenomenological approach would seem to require less processing space. If a great number must be recognized or if the target of interest must be distinguished from a large number of similar targets, the prediction approach would seem to require less processing. Some quantity between one and many will define the crossover where the two approaches are equivalent in their processing space requirements.

Specification of Environmental Characteristics

This task is difficult. Nonetheless, the best possible estimates of environmental scattering characteristics should be attempted. This is especially true when considering parameters in which either the environment (vegetation, etc.) or target is known to have distinguishing characteristics.

Radar Characteristic Differences Determined

In order to recognize a target, regardless of the basic approach used in specifying the target and the environment, the distinguishing differences must be taken advantage of. Omission of the task of determining these differences will subject one to intermittent success at best. This task should be accomplished so that concepts can be developed which will perform dependably and for which some knowledge is available as to the expected success of target recognition under varying conditions. The phenomenological approach attempts to utilize these differences indirectly without formally determining the differences. This determination is the most important analytical step in the prediction approach.

Concepts Generated

Concepts and techniques for implementing concepts, from tried and proven ones to the latest ones, form the pool of instrumental capability with which the characteristic differences can be used to distinguish the target of interest. In addition to this pool of concepts and techniques, the constraints imposed by platform, environmental and operational considerations become a necessary ingredient in generating the concepts. If no appropriate concepts or techniques exist which utilize the target and environmental characteristic differences and meet the constraint criteria, then new concepts and/or techniques may have to be generated. In this case, new does not necessarily mean more sophisticated, complex and costly. Also, one must consider the following possibilities:

1. With a radar sensor it may be impossible, practically speaking and with modern technology, to recognize the target as being unique and different from similar target-like objects.

2. Several concepts and techniques may be required to perform the recognition where each concept or technique individually may be insufficient in that respect.

3. A certain probability of error, targets missed, may have to be accepted in recognizing the target or even in determining the existence of a target-like object.

4. A certain probability of error, erroneous recognition, may have to be accepted in recognition attempts.

Concepts Modeled

Although it may not be absolutely necessary to generate explicit mathematical models of the generated concepts in terms of their effects on the signals of targets of interest and their effects on other signals, an intuitive if not "seat-of-the-pants" approach is the alternative. There is, of course, always a third alternative of being totally dependent on luck. Inadequate performance of this task would probably result in confusion in specifying required radar parameters and in performing simulations.

Computer Simulation

An all out, full-blown computer simulation employing scattering models and processing transfer functions is desirable but not absolutely required. Obviously, a computer simulation would be capable of performing a more exhaustive analysis of the various possible combinations of conditions that could exist. At the very least, some amount of analysis of the response of the candidate approaches to the target of interest under a variety of typical circumstances needs to be performed.

Radars Specified

The radars corresponding to the various candidate approaches should be specified in terms of radar parameters which have been optimized to accentuate the differences on which the approaches are capitalizing. In addition, the radar must also be specified so as to provide the required performance as a sensor and to meet the various system constraints which have been imposed.

Alternative Approaches Selected

Based on the computer simulation or more subjective analyses of the modeled concepts, one or more alternatives are selected. One method of implementing this task is as follows:

1. Establish go/no-go criteria for performance and constraints.

2. Eliminate approaches which do not meet the go/no-go criteria.

3. Establish desirability factors for performance.

4. Weight the remaining approaches as to their relative performance on each criterion and weight criteria relative to each other. The summation of the results is the relative capability.

5. Generate ratios for each approach in terms of the various constraints.

6. Display the results graphically to aid in a relative evaluation of the results.

The following is an example for illustrative purposes only:

1. Criteria go/no-go (range performance $\geq$ 10 km).

System #1	R = 15 km
System #2	R = 9 km
System #3	R =100 km

2. Eliminate System #2. Systems #1 and #3 remain as candidates.

3. Range performance of 10 km is required and performance of 15 km is highly desirable. Additional range performance provides no additional advantages.

4. Relative importance of range performance,

$$P_R = 1 \qquad \sum_{n=1}^{N} P_n = 1 \qquad n = \text{parameter}$$

Adequate performance = 0.1
Inadequate performance = 0.0
Best usable performance = 1.0

$$\sum_{n}^{M} P_n \, P_{Mn} = P_{MT}$$ M = system number.

$P_{MT} \leq 1$

$P_{1T} = 1 \times 1 = 1$

$P_{2T} = 0 \times 1 = 0$

$P_{3T} = 1 \times 1 = 1$

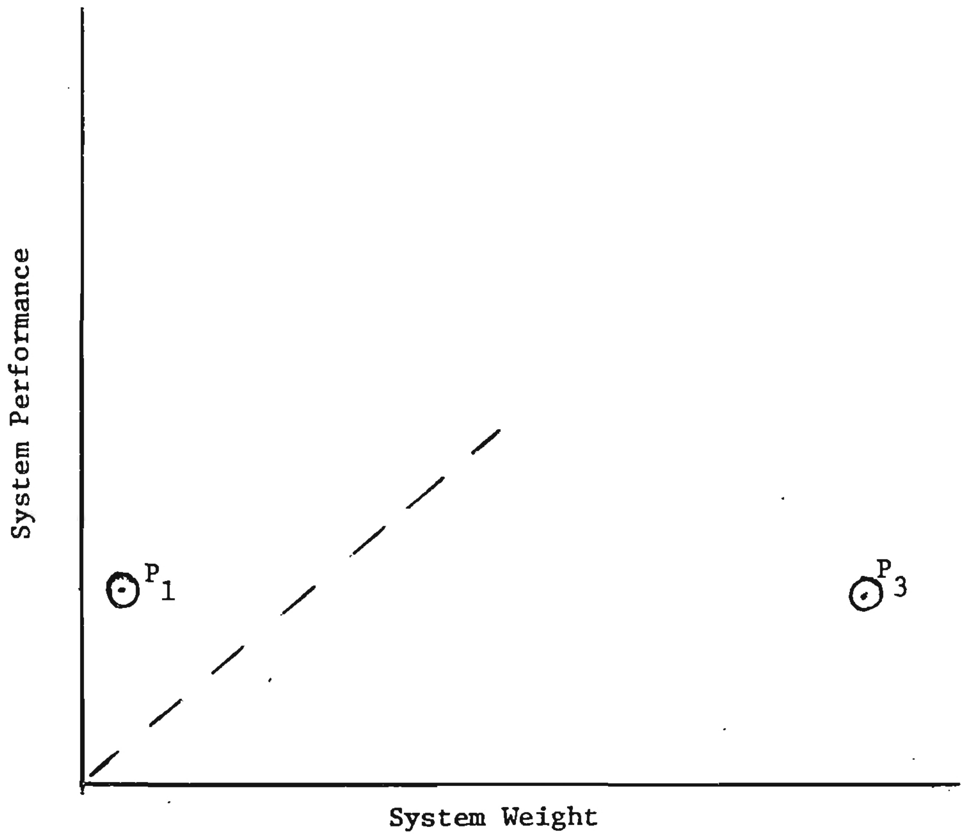
5. Constraint: $W_1 = 200$ lbs.

Weight $W_3 = 4000$ lbs.

$$\frac{P_{1T}}{W_1} = \frac{1}{200} = 0.005$$

$$\frac{P_{3T}}{W_3} = \frac{1}{4000} = 0.00025$$

6.



Seldom will the results be as simple as in the example.

Recognizer Hardware Available

Once one or more alternatives (it is preferable to have more than one at this point) have been selected, they should be configured or developed as appropriate. Premature development of this hardware will probably result in efforts to force fit it as an applicable concept. This approach may work well or it may be more expensive and less productive than starting from scratch. The potential application of existing hardware requires careful and objective analysis. Such analysis may show that the equipment and the concepts that it embodies is completely adequate and provides a step up in attempts to develop recognition systems. On the other hand, such analysis may reveal that certain ones of the several concepts involved are valid and may prove useful as contributing techniques in a new development which employs a group of cohesive concepts and techniques, but that the existing equipment cannot be force fitted to the job adequately. Worse yet, the analysis could reveal that what appears to be mysterious or magical is really a cloak of inadequacy.

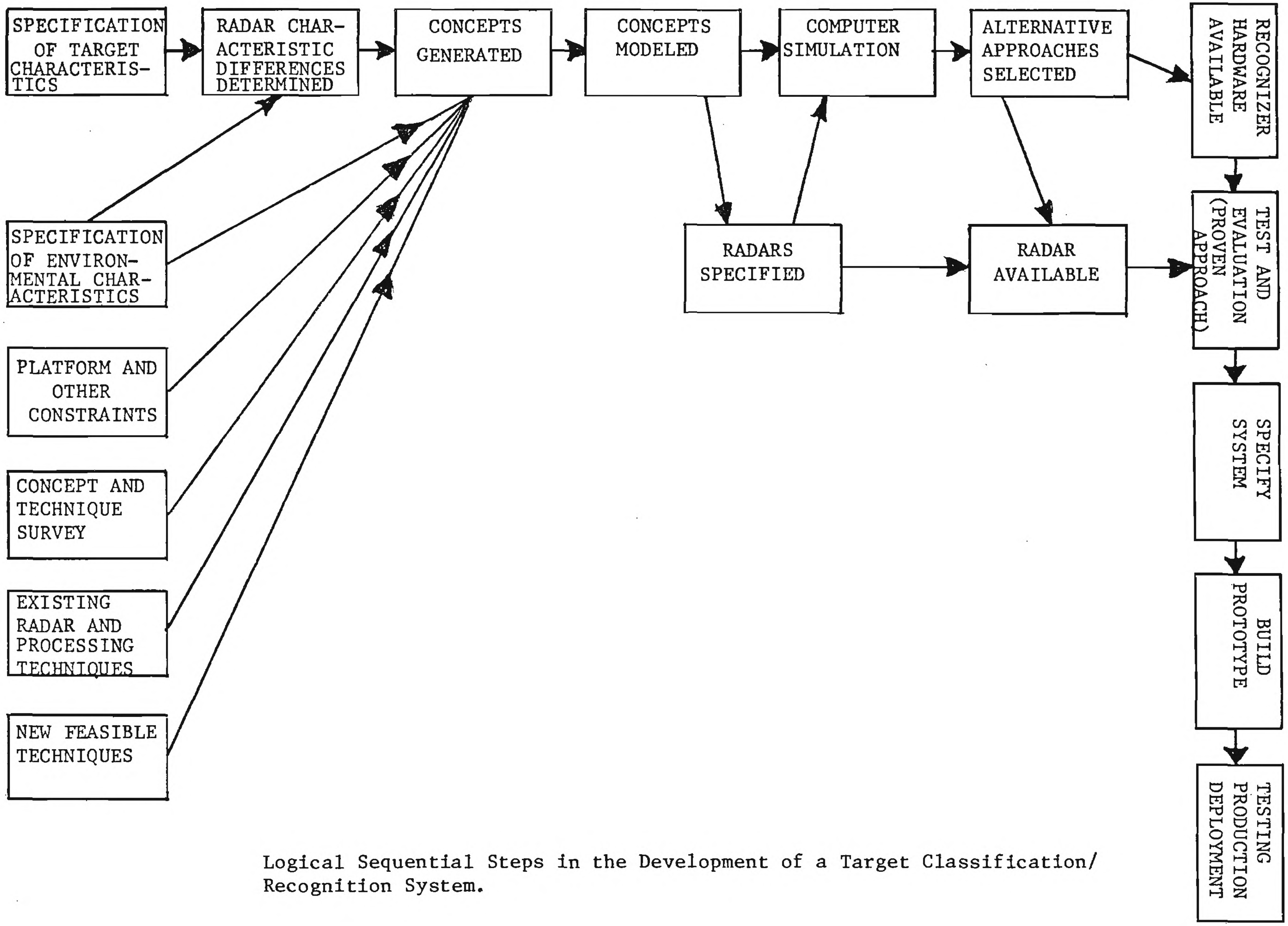
Test and Evaluation

Both recognizer and radar hardware must eventually be made available to prove the real world performance of the concepts selected. Hopefully, the radar equipment configuration will have been based on the basic approaches selected. If not, erroneous though possibly impressive results could be achieved. Such results would apply only to one particular day under a specific set of conditions. The danger in this is in the false security such results could impart that "we're on the right track." For consistent results under varying conditions and realistic changes in those conditions a firm understanding of why results are achieved is important. Unacceptable delays could occur in such a program if future prototypes failed to produce the same kind of results, or if the T and E model varied considerably in its results, without justifiable explanation.

It is important in this phase to determine the testing and evaluation technique in advance and then to monitor and evaluate results objectively. Otherwise, the techniques for testing and the methods of evaluation could unwittingly be selected to support or bias the experiment toward the desired results.

Specify System

This task is a natural follow-up task to the test and evaluation task. This task is essentially one of defining the concept and techniques (which may not be identical with the starting concept and techniques) which have to be selected and proven. Such definition is accomplished by descriptive verbiage, diagrams, drawings and calculations. If such definition cannot be accomplished, it is a warning that the concepts and techniques that are being employed, perhaps successfully, are not well enough understood to progress to the prototype phase. To advance to the prototype phase in spite of a lack of definition would be risky.



Logical Sequential Steps in the Development of a Target Classification/ Recognition System.

A-1723

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

22 September 1975

U.S. Army Missile Command
Advanced Sensors Directorate
RF Guidance Section
Redstone Arsenal, Alabama 35809

Attention: A. H. Green, Jr.

Subject: Research and Development Contract Status Report No. 5
"Design Analysis for Implementation of Polarization
Agility with Target Recognition"
Contract No. DAAH01-75-C-0639
Covering Period 1 August 1975 through 31 August 1975

Gentlemen:

Technical Progress

Activities during this period have been devoted primarily to development of material to be incorporated in the final report. In addition, several conversations were held with MICOM and Navy personnel concerning the potential use of a Navy-owned short pulse radar in the target recognition measurement program. A pulse width of 10 nsec had been established as the desired value in the event that the radar was to be used. Normally, the radar has a 0.6 nsec pulse; however, it has been established that a 10 nsec pulse width is achievable. As of this reporting period it appears that the radar will not be required by MICOM, thus tentative arrangements to borrow the radar were cancelled.

Trips

At MICOM's request, Mr. J. L. Eaves and Mr. J. M. Schuchardt visited MICOM on 7 August 1975 to observe target recognition data collection efforts. The intended data collection was not accomplished at this time because of a radar failure. A failure in the local oscillator power supply was the apparent problem. MICOM personnel initiated efforts to correct the problem. Program review discussions were held with Mr. Nelson and Mr. Harraway of MICOM. Also Mr. Eaves and Mr. Schuchardt visited the data collection field site to review the target area and radar equipment.

Mr. B. C. Appling of the Radar Technology Division of the Engineering Experiment Station at Georgia Tech visited MICOM on 19 August 1975. Mr. A. H. Green, Jr., of MICOM and Mr. Appling had discussions concerning the status of the program, the on-going target recognition data gathering and modifications to an available radar.

Later Mr. Green and Mr. Appling held discussions with personnel from Bendix who had collected data for hyperplane modeling for target recognition. The following information was provided concerning the data taking:

- o Target data were taken continuously in azimuth from 0^{o} to 45^{o} in azimuth at 3 ranges (2.4 μs → 393 yd; 3.1 μs → 508 yd; 3.7 μs → 606 yd).
- o The estimated signal-to-clutter ratio was $\geq$ 20 dB. (The stated reason for the high s/c ratio was to permit the collection of very clean signatures.)
- o No s/c or clutter level was established.
- o At each azimuth-range combination, transmisssions were made with vertical polarization with two receive configurations; 0^{o}, 90^{o} and $+45^{o}$, -45^{o} polarizations with respect to the transmitted polarizations were received.
- o The above procedure was repeated for horizontally polarized transmissions.
- o Bendix personnel estimated that from 5 thousand to 10 thousand signatures had been obtained.
- o The pulse width during data collection was stated to be about 18 ns.
- o The following clutter recordings were made for clutter modeling.
  - o o Clutter recordings were taken for the same polarization combinations as for the target.
  - o o Wooded target areas were taken as clutter at 3.1 μs, 3.4 μs, and 4.5 μs ranges.

During the discussions that followed, Bendix personnel provided the following information:

- o It is not possible with the current technique to differentiate between two targets within the azimuthal resolving ability of the radar.
- o Five recognition hyperplanes will be modeled for each polarization.

It was noted throughout these discussions that the word "discrimination" was used a great deal where "recognition" should have been used. Usage of these terms has specific meaning in connection with the MICOM recognition activity and should be adherred to. As used in connection with the MICOM activity these words are believed to have the following definitions:

Discrimination - distinguishing between target-like objects and non-target-like objects or scattering sources.

Recognition - identification of a specific target by differentiating between characteristics of the specific target and other target-like objects.

Techniques which are well suited for recognition may not be suitable for discrimination and vice versa. Furthermore, recognition techniques may depend on the discrimination having already been accomplished.

Future Efforts

Georgia Tech personnel plan to travel to MICOM to observe target recognition evaluation data gathering.

A final report will be completed which documents the work completed under Contract No. DAAH01-75-C-0639.

Georgia Tech is prepared to commence work under a Change-in-Scope of Contract DAAH01-75-C-0639.

Respectfully submitted,

B. C. Appling
For J. L. Eaves,
Project Director

Approved:

H. A. Ecker
Director
Applied Engineering Laboratory

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The objective of this program was to examine the performance of various radar configurations involving polarization agility and target recognition. In particular, the performance is examined in terms of target-to-clutter ratio for a radar sensor having polarization agility and target recognition with respect to a radar sensor having polarization ability only, target recognition only, and neither. Targets of interest included military tanks, trucks, jeeps, and personnel carriers.

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ABSTRACT

The objective of this program was to examine the performance of various radar configurations involving polarization agility and target recognition. In particular, the performance is examined in terms of target-to-clutter ratio for a radar sensor having polarization agility and target recognition with respect to a radar sensor having polarization agility only, target recognition only, and niehter. Targets of interest included military tanks, trucks, jeeps, and personnel carriers.

FINAL TECHNICAL REPORT

DESIGN ANALYSIS FOR IMPLEMENTATION OF POLARIZATION AGILITY WITH TARGET RECOGNITION

EES/GIT PROJECT A-1723

Prepared for:

UNITED STATES ARMY MISSILE COMMAND
REDSTONE ARSENAL
ALABAMA 35809
UNDER
CONTRACT DAAH01-75-C-0639

By

B. C. APPLING and J. L. EAVES

JUNE 1976

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
Atlanta, Georgia 30332

FOREWORD

This research program designated as Georgia Tech Project A-1723, entitled "Design Analysis for Implementation of Polarization Agility with Target Recognition," was carried out by personnel of the Radar Technology Division of the Applied Engineering Laboratory, Engineering Experiment Station, Georgia Institute of Technology, Atlanta, Georgia. The research was conducted during the period of 7 March 1975 through 31 August 1975 under the general supervision of Dr. H. A. Ecker, director, Applied Engineering Laboratory, and Mr. J. L. Eaves, chief, Radar Technology Division. Mr. B. C. Appling served as project director. The program was sponsored by the U. S. Army Missile Command, Redstone Arsenal, Alabama. Mr. A. H. Green, Jr. of USAMICOM, served as project engineer, and to him Georgia Tech expresses gratitude for his assistance and guidance throughout the research program. In addition, Georgia Tech acknowledges the support and interest of Mr. C. H. Cash and members of his staff at USAMICOM.

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1. INTRODUCTION

The objective of the analysis reported here was to examine the performance of various radar configurations involving polarization agility and target recognition. In particular, the performance is examined in terms of target-to-clutter ratio for a radar sensor having polarization agility and target recognition with respect to a radar sensor having polarization agility only, target recognition only, and neither.

2. POLARIZATION AGILITY IMPLEMENTATION

On 22 April 1975 Georgia Tech personnel visited Benedix in Baltimore, Maryland, for the purpose of reviewing proposed plans for modifying the Benedix breadboard target recognizer for polarization agility operation. As a result of this visit, it was determined that the polarization implementation was planned as follows:

The target recognizer in conjunction with the radar would utilize two antennas--the original antenna for transmission and a second antenna for reception. The feed for the original antenna would be oriented such that either horizontal or vertical polarization could be selected for transmission. The second antenna, or receiving antenna, would employ a dual-polarized feed and a ferrite switch such that horizontal or vertical polarization on reception could be selected on a pulse-to-pulse basis. Also reception on an alternate pulse basis of $\pm$ 45° linear polarization would be possible by mechanically rotating the feed system. It was Georgia Tech's conclusion that such a technique was feasible. This was eventually borne out in the actual implementation.

The test configuration was to be used in gathering data which would show what advantages, if any, would be realized from using polarization agility with target recognition. The test configuration as previously mentioned consisted of manual agility during transmit and automatic agility during receive. The envisioned operational configuration would have automatic agility both on transmit and receive and use those polarization agility techniques which may have been shown from tests to have enhanced target discrimination when used in conjunction with recognition.

3. ANALYSIS OF VARIOUS RADAR CONFIGURATIONS

3.1 Definition of Discrimination and Recognition. As used herein, discrimination is defined as the process of separating target-like objects from clutter. As used herein, recognition is defined as the process of distinguishing the precise target class from similar object classes. These definitions are important since target discrimination performance improvement is to be analyzed. An example will help to further define the difference between discrimination and recognition as used herein. If an operator using a suitably equipped radar system is able to state that an object is a man-made object as opposed to clutter, then the product is considered to be target discrimination. If the operator is able to state that the object is a jeep rather than any other man-made object or clutter, then the product is considered to be target recognition.

3.2 Configuration Definitions. The four configurations for which target discrimination performance will be compared are as follows:

3.2.1 Radar with neither polarization agility nor target recognition equipment.

3.2.2 Radar with polarization agility.

3.2.3 Radar with target recognition and without polarization agility.

3.2.4 Radar with both target recognition and polarization agility.

3.3 Target Discrimination Alone. Figure 1 shows a block diagram of a simple radar discrimination system. The radar transmitter transmits the radar energy which is subsequently scattered by the target. The backscattered energy from the target is received by the radar receiver. During the intermediate frequency stage automatic gain control is applied. Following amplification and automatic gain control at the intermediate frequency stage, second detection occurs in the block labeled "video detector." The analog video threshold allows only video exceeding a certain voltage level to be passed to the CRT. Ideally, target video would exceed the threshold while noise and clutter video would not. In actuality, this is seldom the case.

Finally, the video passing the video threshold is displayed on a CRT. This video is then viewed by the operator who makes a decision. The operator's decision may be considered as the final discrimination step.

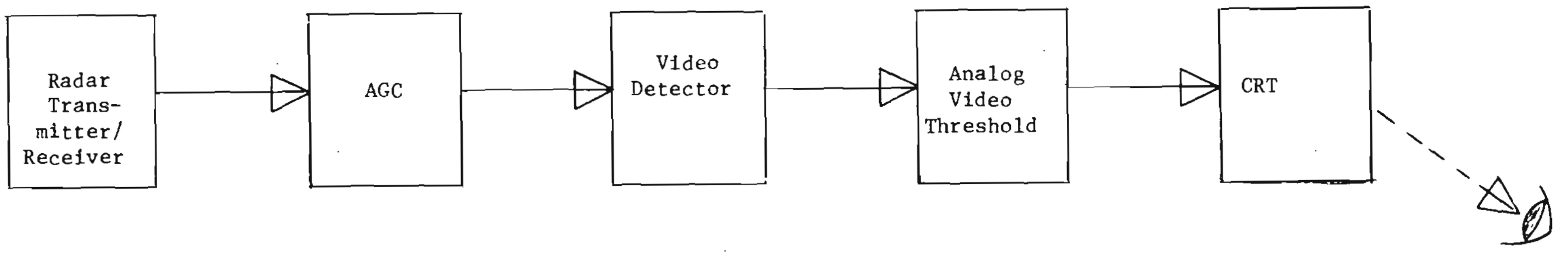


Figure 1. Simple Radar Discrimination System (No. 1)

The chracteristics for this simple radar discrimination system are shown in Table 1. For a system with these parameters there are up to 200,000 resolution cells. If only one radar resolution cell existed and if it were known apriori that if a target existed that it would be in this cell, then the problem would be to determine whether or not the target existed in this single cell. Under conditions when the target was not within the cell, an operator would have a certain probability of reporting incorrectly that a target did exist.

Table 1

Characteristics of Simple Radar Discrimination System

Transmitter Peak Power (P_T)	25KW
Transmit Pulse Width ( )	30 ns
Antenna Gain (G)	45 dB
Antenna Azimuth Beamwidth (Θ_3)	1°
Range Coverage for Targeting	500 M to 10,500 M
Receiver Noise Figure (N_f)	8 dB
Other System Losses	6 dB
Azimuth Coverage	$\pm$ 45°
Scan Rate	180°/s
Pulse Repetition Frequency (f_r)	3600

If we ignore the psychology of the operator himself, then the rate at which false reports would be made, called the probability of false alarm, would be determined by the setting of the threshold circuit. By using CFAR receiver design or certain video techniques, an adaptive threshold may be established such that the false alarm rate resulting from clutter is constant.

If the target is then placed within the resolution cell, the probability of detection will depend upon the target-to-clutter ratio. It would also, of course, depend upon many other factors such as the probability distributions and fluctation characteristics of both clutter and target. Though less obvious, it would also depend upon the signal-to-noise ratio and the clutter-to-noise ratio.

Clutter has been modeled in many different ways. Different models are more accurate in describing different types of clutter. Some amplitude distributions that have been used by various investigators to describe or model clutter statistics include Rayleigh, Rice and Log-Normal. It is not an objective of this report to advance the best clutter model. Instead a simplified clutter model will be used to facilitiate the relative comparison of the performance of simple radar, radar with polarization agility, radar with recognition, and radar with both recognition and polarization agility.

In the analysis that follows it is assumed that the amplitude statistics of the clutter return from one particular cell are Rayleigh distributed; in addition, it is assumed that the amplitude fluctuates on a scan-to-scan but not on a pulse-to-pulse basis. These simplifying assumptions permit us to treat the clutter from a particular cell in a manner similar to a Swerling Case 1 target; we will treat the target as a Swerling Case 5 type target, which corresponds to a nonfluctuating cross section [1]. Under these simplifying assumptions and with the following visibility parameters, the target-to-clutter ratio is calculated to be 4.84 dB. Details of this and other calculations are given in the Appendix.

3.3.1 Assumed Visibility Parameters:

$$P_{fa} = 0.1$$

$$P_{d \text{ for clutter}} = 0.1 \text{ (Swerling 1)}$$

$$P_{D \text{ for target}} = 0.95$$

If the probability of false alarm due to noise is set at a more reasonable figure, say 10^{-6} and all other parameters remain the same, the required target-to-clutter ratio is calculated to be 4.70 dB. This value will be used to represent the discrimination capability of the basic radar for a single resolution cell when the target's position is known apriori.

As stated before, there are many resolution cells within the radar's coverage area. The operator's task would be hopeless if he had to contend with a 0.1 probability of clutter detection for each resolution cell. It has been reported that a typical radar operator has an equivalent bandpass on the order of several Hertz [1]. With the realization that 20,000 separate resolution cells are interrogated each one second (antenna scan) and that the information bandwidth of a typical operator is only on the order of several Hertz, we can see that the frequency of clutter detection for a given resolution cell must be reduced to the order of 10^{-6}. For a clutter alarm rate at this level a false alarm rate due to noise equal to 10^{-6}, a target detection probability of 0.95, we calculate the required target-to-clutter ratio to be 12.59 dB.

3.4 Target Discrimination with Polarization Agility. The configuration assumed for a radar with polarization agility is shown in Figure 2. The polarization agile radar transmits with vertical and horizontal polarization on alternate transmissions. Either (or both) the parallel and cross polarization components is used on receive. AGC and a video detector are employed as in the case of the simple radar discrimination system. Between the detector and the CRT two signal processing alternatives are shown. The following discussion deals with the threshold/CRT processing alternative, in accordance with the technical requirement for this report. The other alternative which involves Stationary Target Indication (STI) processing is discussed in Section 4.

On first consideration it would seem that the polarization agility would cause pulse-to-pulse amplitude fluctuations on the clutter return such that a Swerling Case 2 model could be used in calculating the clutter-to-noise ratio required for clutter detection. Perhaps a more accurate model for this case is to consider the returns for two polarizations as two separate pulse trains which are interwoven on an alternate pulse basis. If the clutter signal power for the two separate pulse trains are assumed to be independent, then the magnitude of the composite

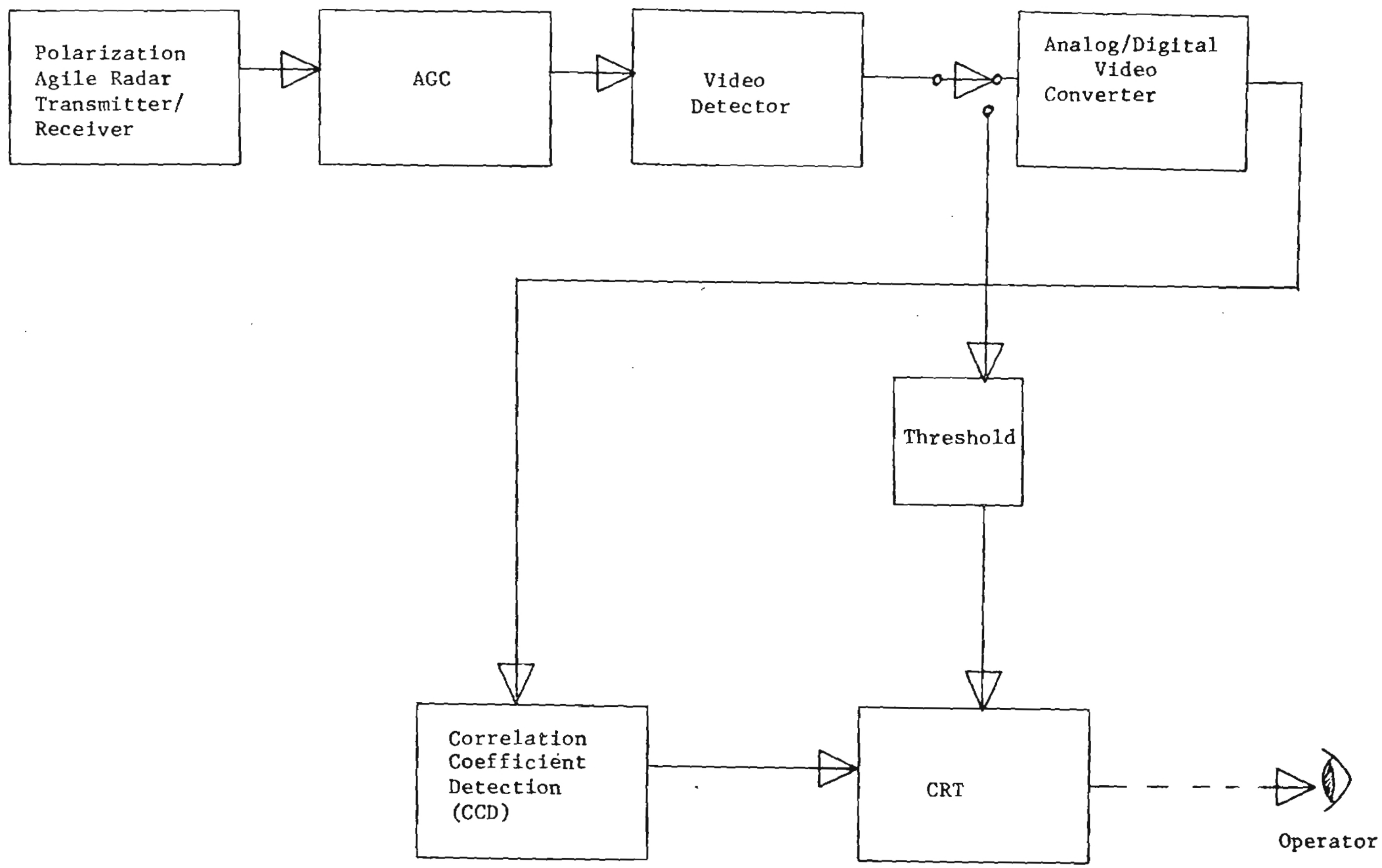


Figure 2. Radar With Polarization Agility

clutter signal is equal to the square root of the sum of the squares of the two trains. If each pulse train has pulse-to-pulse correlation, Swerling Case 1 assumption, then the resultant composite clutter signal will be predominantly pulse-to-pulse correlated.

Unlike the clutter case, the alternating pulse trains will be highly correlated in the case of the target. Thus, the composite target signal is derived from the addition of the two pulse trains. The resultant target signal-to-noise ratio will not fluctuate since it results from summing two non-fluctuating signals.

Under the same assumptions used in the analysis of the simple radar, the required target-to-clutter ratio with polarization agility is calculated to be 3.19 dB (see Appendix A). This corresponds to a 1.51 dB decrease in the required target-to-clutter ratio or, from another viewpoint, amounts to an increase of 1.51 dB in effective target-to-clutter ratio.

For the multicell case where the target's position is not known apriori the required target-to-clutter is calculated to be 11.08 dB for the polarization agile radar. Recall that 12.59 dB was calculated for the simple non-agile radar. Thus, polarization agility reduced the required target-to-clutter ratio by 1.51 dB or, from the other viewpoint, an effective increase of 1.51 in target-to-clutter ratio results due to the use of polarization agility.

There are several reasons why these results must be considered relative and not absolute:

3.4.1 The clutter model is only an approximation.

3.4.2 Certain losses such as CFAR losses and beam shape losses are not accounted for.

3.4.3 Possible partial decorrelation on a pulse-to-pulse basis was not considered.

3.4.4 The potential inefficiency in combining two pulse trains to form one composite pulse train was not considered.

The improved performance for the polarization agile radar as compared to the simple radar is not very significant. However, it should be remembered that the assumed radar configuration with polarization agility does not include additional discrimination processing, which would increase performance.

3.5 Target Discrimination with Target Recognition. Actual performance data on the discrimination capability of the target recognizer used with the simple radar was not available at the time of this report. However, it can be concluded that the target recognizer's ability to discriminate will be at least as good as its ability to recognize, since discrimination is an inherent part of recognition.

Figure 3 shows the assumed system configuration with recognition. Obviously the simple radar is a subset of this configuration. The radar with recognition will therefore have discriminating capability at least as good as the simple radar.

Since the recognizer operates on the principal of distinguishing the appearance (range profile) of the target from the appearance of clutter and other non-target objects, it is concluded that recognition performance will be seriously degraded as the target signal level approaches the clutter signal level. Because low signal-to-clutter results in an alteration of the statistical characteristics and profile appearance of the cell that contains the target, the limit for target recognition based target discrimination may occur for a signal-to-clutter ratio on the order of OdB. This consideration, of course, is for apriori knowledge of a suspect target in a single cell.

In the case where the location of a possible target is not known apriori, the multicell case, the radar with target recognition must be treated in a fashion similar to that for the simple radar and for the radar with polarization agility. This consideration raises the question of discrimination processing data rate. In the cases of the simple radar and the radar with polarization agility, the basic discrimination rate is equivalent to the scan rate of the radar. However, this is not necessarily true for the radar with target recognition. From the information available it can not be determined if the recognition technique permits real-time recognition and discrimination, i.e., as in the case of a CRT presentation, which would be used with a simple radar or a radar with polarization agility. If real-time recognition/discrimination cannot be accomplished then the number of resolution cells processed per scan divided into the total number of cells to be processed

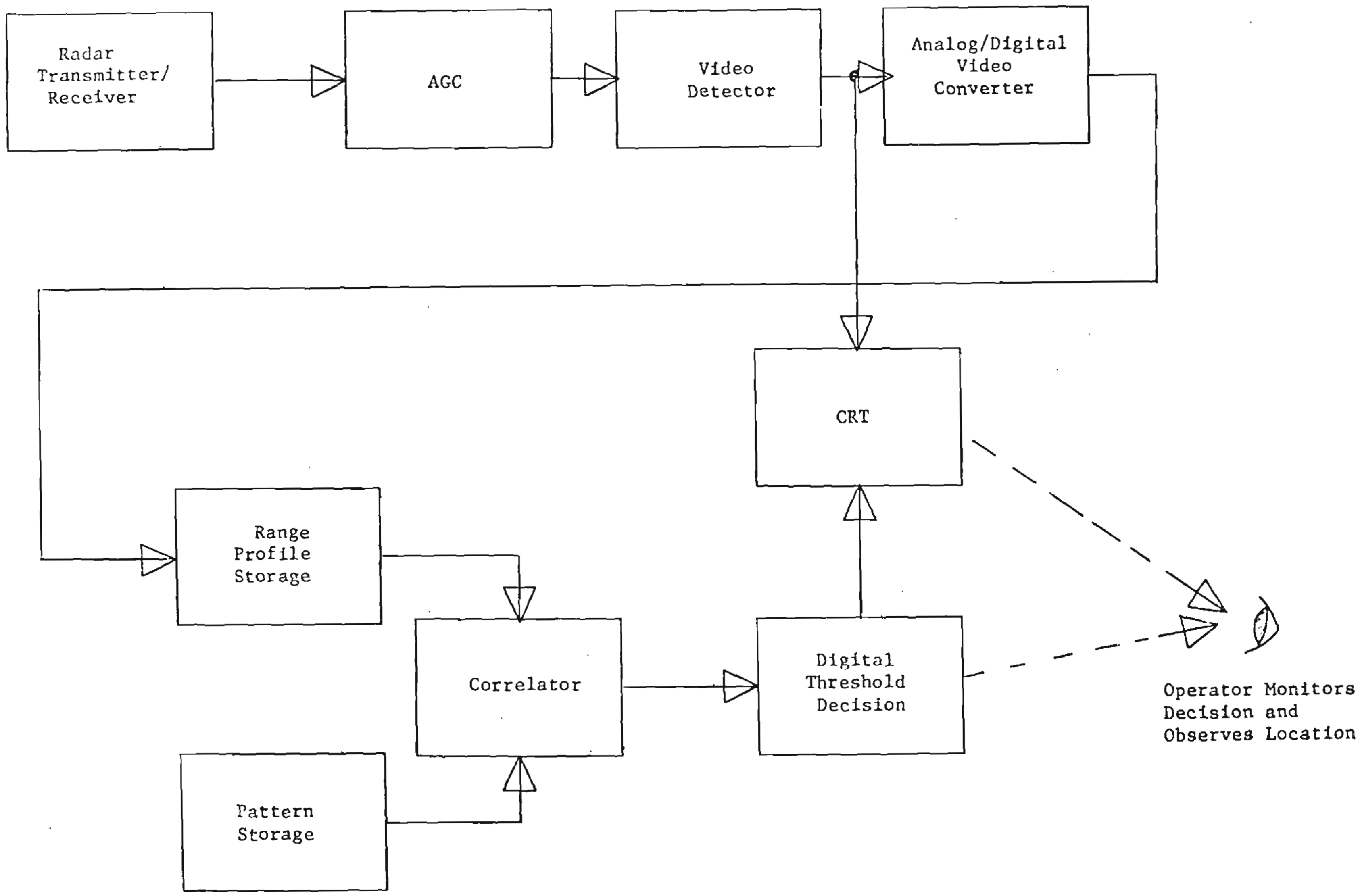


Figure 3. Radar With Recognition

would yield the number of scans necessary to achieve total coverage. This information can be related to time by multiplying the result by the time required for a single scan.

3.6 Target Discrimination with Both Target Recognition and Polarization Agility. Figure 4 shows a possible configuration that includes both recognition/discrimination and polarization agility. Two alternative paths for polarization agility discrimination are indicated one with Correlation Coefficient Discrimination (CCD), and the other a conventional amplitude threshold processing. The target recognition portion of the system includes range profile storage, pattern storage, signal correlator, and digital threshold decision logic. The recognition system may receive an input signal from radar directly or from the output of the CCD discrimination processor.

Obviously the discrimination capability of a system configured in this manner will be at least as good as any of the system configurations discussed previously. This is so because each of the previous configurations are contained as subelements of this configuration. Again, as in the case of the radar with recognition system, insufficient data are available to judge the discrimination capability of polarization agile radar with recognition system. Quantitative data as to the target level and in-cell clutter level is required for-determining the target-from-clutter discrimination capability for both configurations which include the target recognizer. Good performance has been reported for target-to-clutter ratios of 4.5dB. The writer has seen the recognizer discriminate (not recognize) for target to adjacent cell clutter ratios of approximately 12 dB.

There is a basis for performing one simplex comparison of this configuration with a basic radar with recognition. This basis is the use of a vertical and the horizontal polarizations to form two separate profiles. The total pulse energy for vertical polarization and the total pulse energy for horizontal polarization may be closely correlated in the case of a target scatterer. However, the two profiles are likely to be

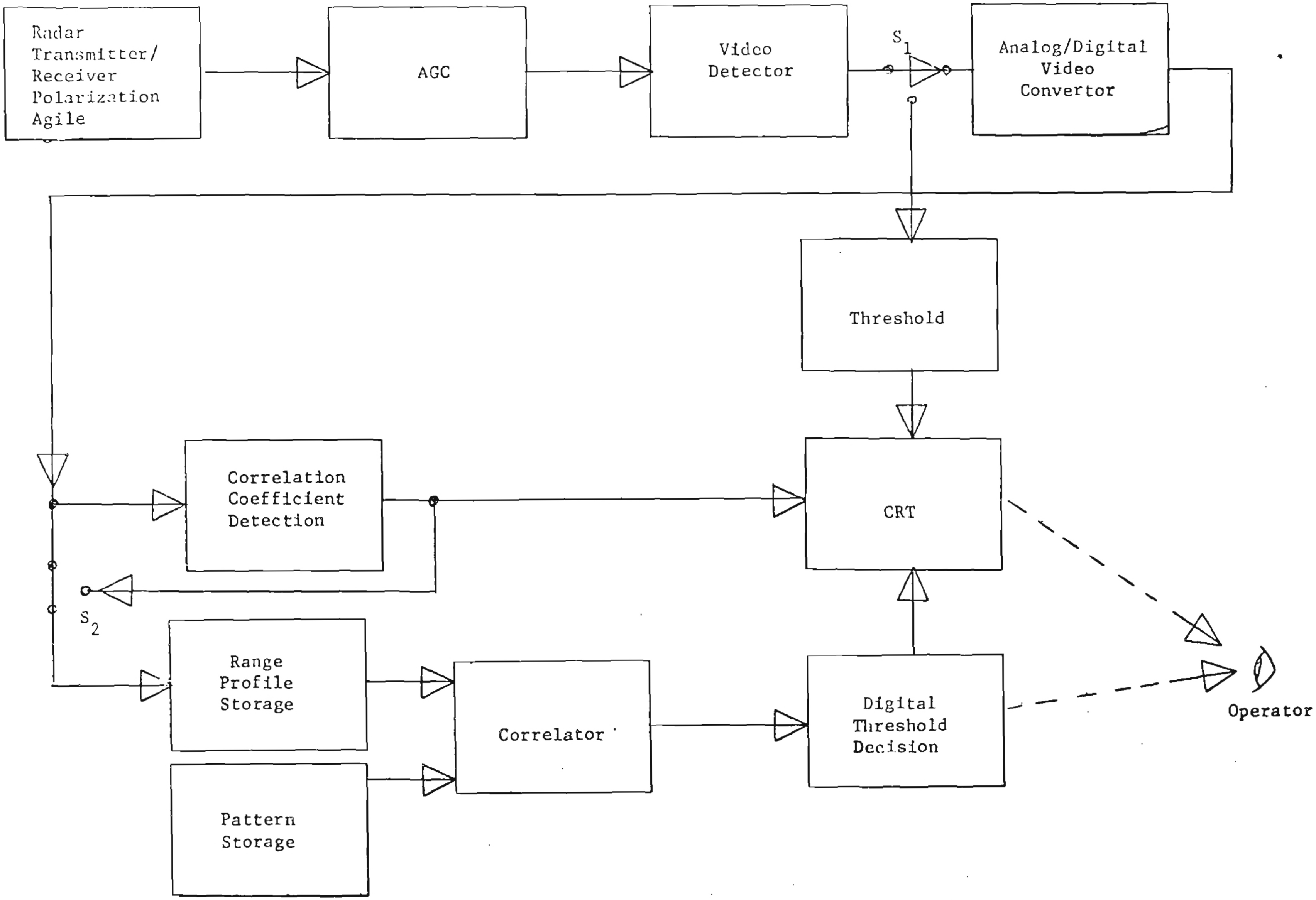


Figure 4. Polarization Agile Radar with Recognition

considerably different. This should cause the net ability of target detection to increase to near unity. Conversely, for the same probability of detection as used before, 0.95, a lower target signal-to-clutter signal ratio would be required.

As discussed for the other recognition system configuration, the total number of cells to be processed and the cell processing rate must be taken into account to ascertain the time required for total coverage.

4. ADDITIONAL CONSIDERATIONS

4.1 Design Configurations for Target Discrimination and Recognition. During the earlier part of the contract period, several design configurations were designed as possible methods for integrating a polarization agile radar with recognition and with discrimination processing for envisioned operational systems. These configurations are shown in Figures 5 through 7.

Figure 5 is a fairly conventional radar configuration which would be appropriate if a single pulse width were satisfactory for both Stationery Target Indication (STI) processing and Target Recognition (TR) processing. The TR processor is shown being gated on by the STI discrimination processor. This reduces the processing rate required of the TR processing. As shown the TR processor has the option of using either single or dual polarized returns.

The STI processors, as currently designed, require pulse widths of approximately 50 nsec minimum. Various pulsewidths have been mentioned as being desirable for the recognition equipment. Figure 6 shows a possible radar configuration if the STI and TR processors require different pulse widths. This configuration has the advantage of a single transmit device and design simplicity.

Figure 7 shows an alternative for achieving two pulse widths with a single transmit device. Not shown is the obvious alternative of using two transmit tubes to achieve the two pulse widths.

In configuring these hypothetical systems, it became apparent that one of the greatest problem areas was in the selection of the pulse width. Different pulse widths were mentioned as being optimum; among them being 30nsec, 15nsec, 5-10nsec, and 1 nsec. These pulse widths

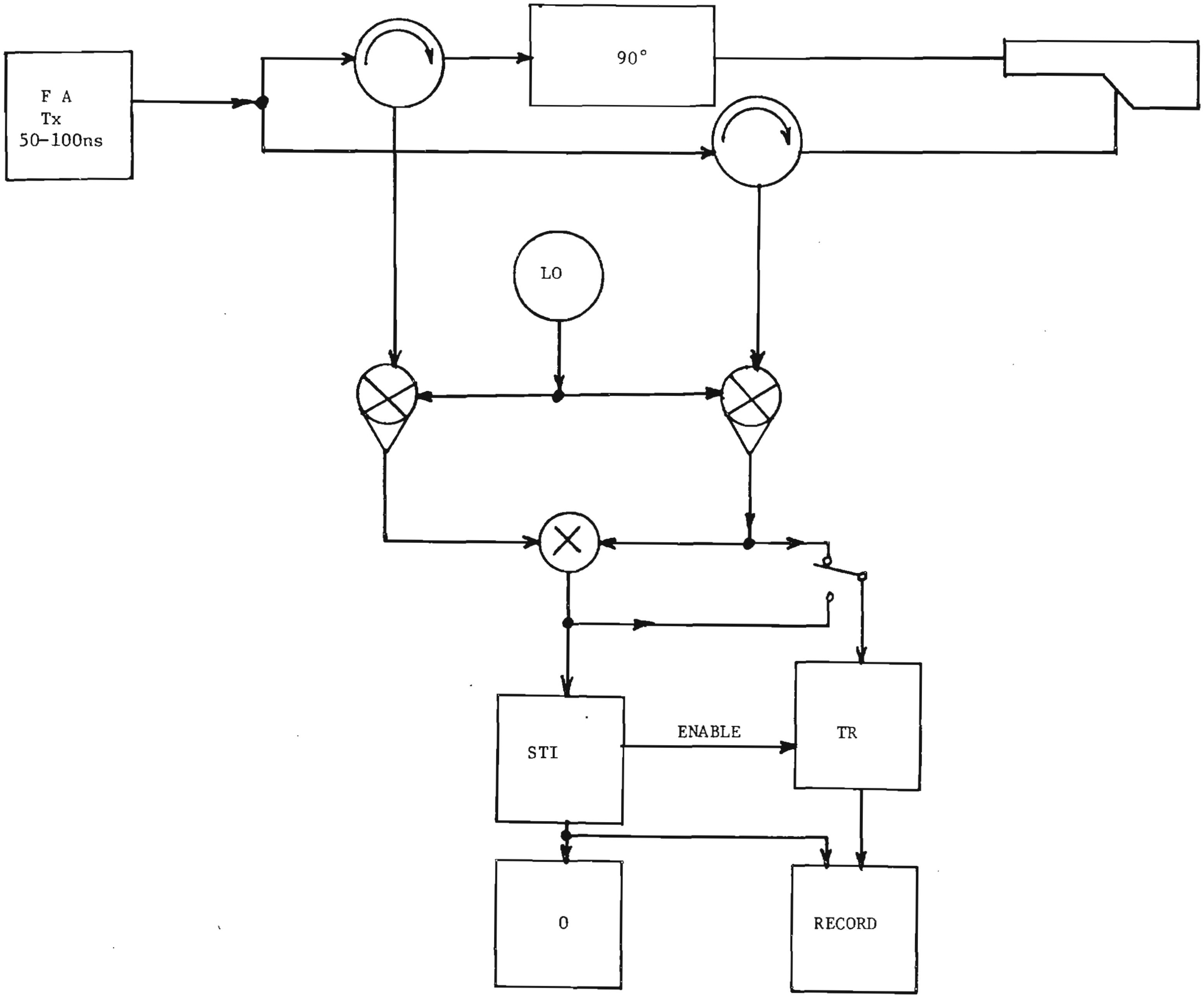
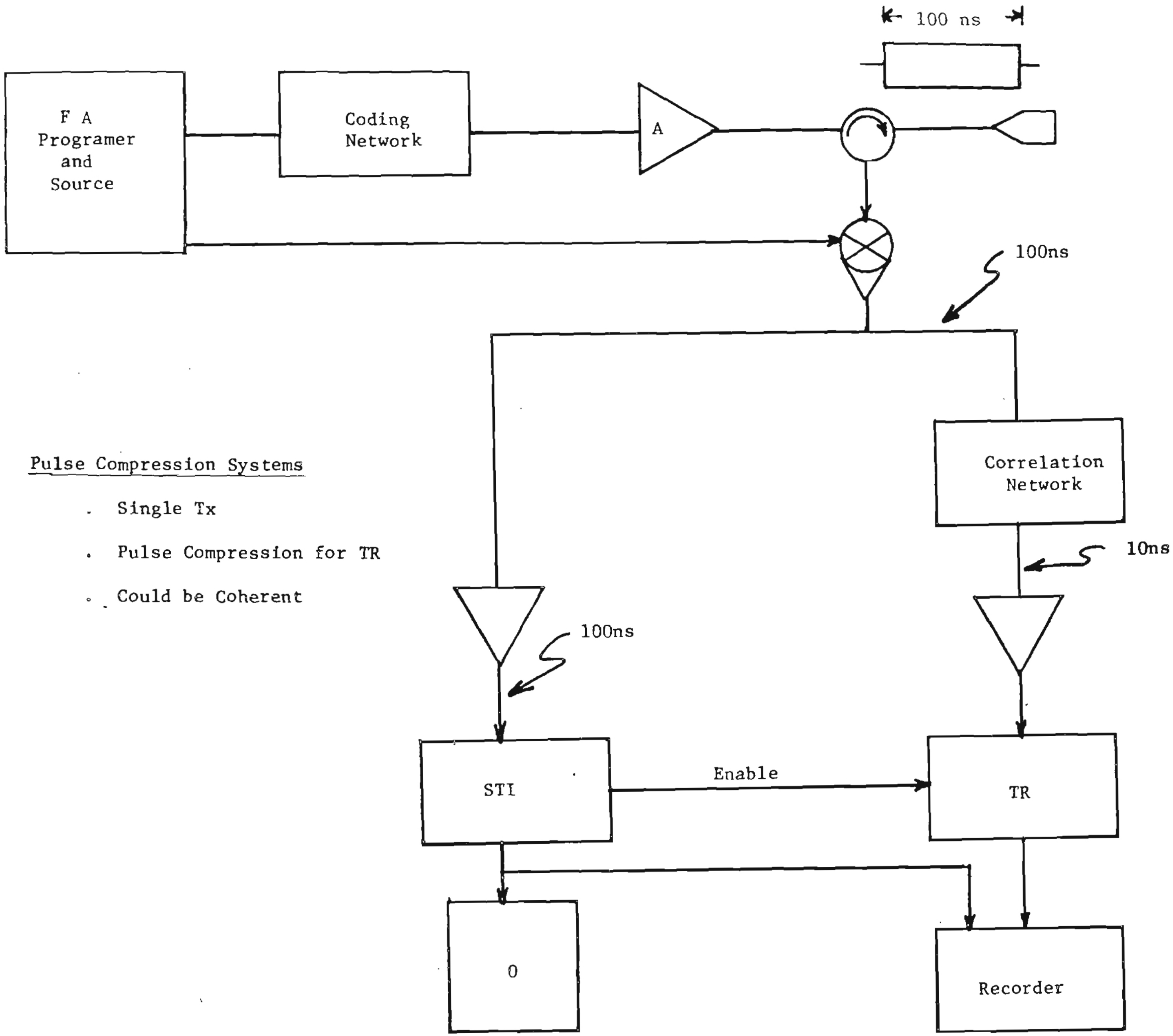


Figure 5. Single Pulse Width System



<u>Pulse Compression Systems</u>

- Single Tx
- Pulse Compression for TR
- Could be Coherent

Figure 6. Pulse Compression Systems

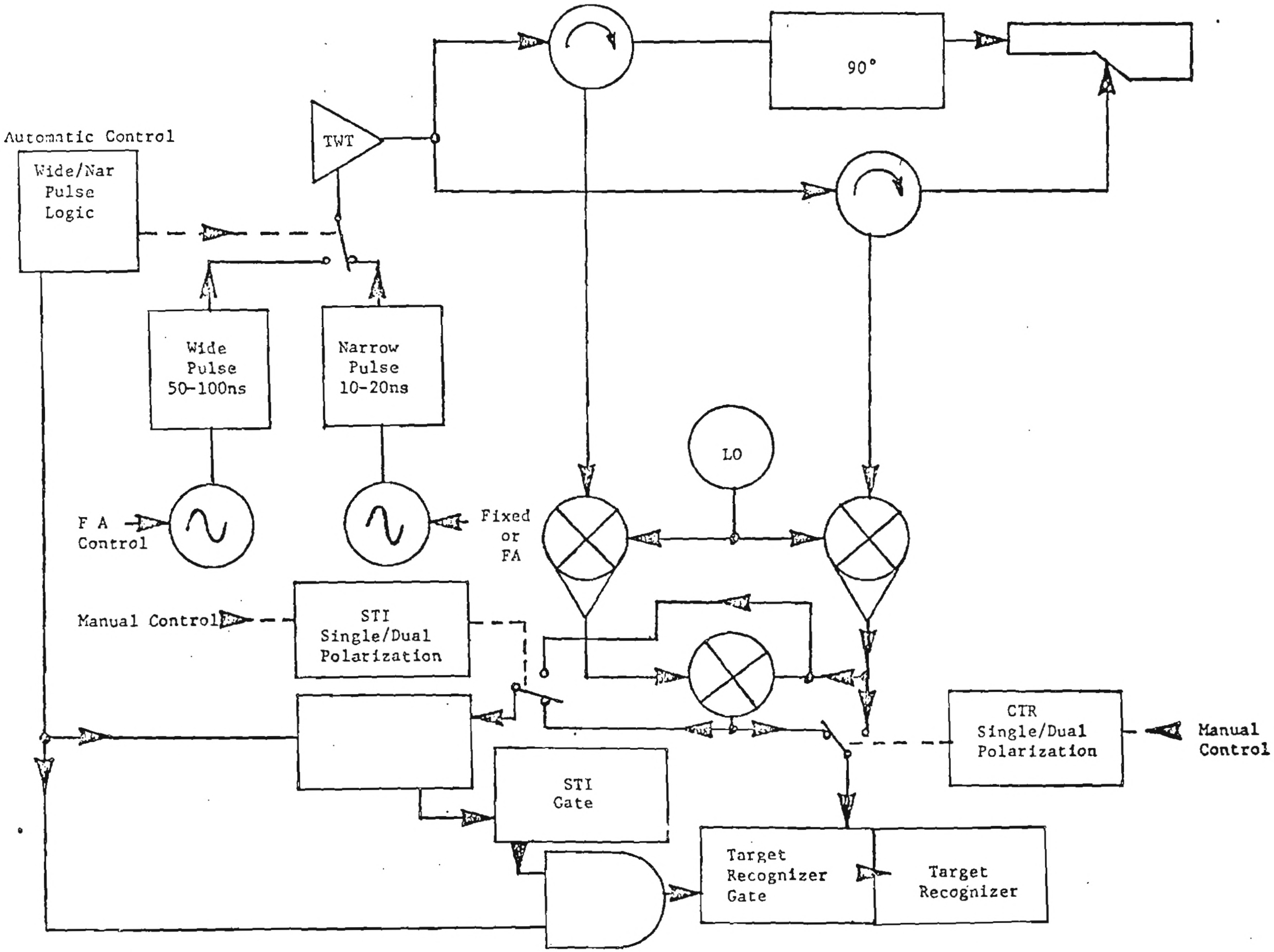


Figure 7. Dual Pulse Width System

were stated as desirable but were incompatible with the polarization agility discrimination processors envisioned for the operational system. This led to the short pulse study which is summarized in the next subsection.

4.2 Short Pulse Study. The short pulse analysis was commenced with the objective of defining the optimum short pulse width for range profile recognition purposes. It was assumed that scattering centers which significantly contribute to the range profile of a target must be resolvable from each other. This premise is considered to be a necessary, but not sufficient, condition to perform target recognition with the range profile technique and simple pulse radar equipment. The definition of a pulse rise time and pulse width were established. Range accuracy was related to rise time and consequently to bandpass instead of pulse width for the conventional pulse radar. Differentiation was made between range accuracy and range resolution.

An expression was defined which serves as a figure of merit for resolving ability (resolving power ratio). The characteristics of the ratio were defined for a rectangular pulse for comparison purposes.

It was shown that amplitude modulation of the pulse (which increases bandwidth) resulted in an improved resolving ability, for a particular pulse width. The effects of amplitude modulation of an otherwise rectangular pulse were generalized by defining a correlation index. It was shown that if sufficient decorrelation were achievable, two targets or scattering centers of one target were mutually resolvable regardless of pulse width.

Some special considerations that should be appreciated when dealing with short pulse widths were quantitatively defined. It was shown that pulse widths corresponding to the distance between scattering centers on a target result in greater variations in the target's profile than would with either longer (with wide bandwidth) or shorter pulses. From a profile complexity viewpoint, it appears that pulse widths less than 1 nsec or greater than 30 nsec, with wide bandwidths would be more favorable than those in the 1-30 nsec region. When the range extent of the pulse was on the same order as scatterer spacing, small changes in pulse width resulted in large variations in the profile appearance. A similar result would occur if the pulse width were held constant and the target's aspect were varied slightly. Larger pulse widths were not as sensitive to these variations.

The effect of jitter, multipath, waveguide transit time, processor speed and pulse-to-pulse processing were briefly considered. Sampling rate requirements were found to be high. Waveguide transit time was found to be of importance for such short widths. Such effects should be considered in RF plumbing design in an operational system. Profile variation due to multipath phenomena was assessed.

Many of the phenomena discussed are believed to have a compound effect in reality though each was assessed independently. Also not all phenomena are strictly limited to causing problems at short pulse widths.

A list of alternative means of generating short pulses was prepared and the most obvious and straightforward ones were recommended (capable component and amplification of short pulse generated at a low power). A list of available components was prepared. As a result of this analysis, a pulse width of 30 nsec was stated as appearing to be the most suitable pulse width.

4.3 Discrimination and Polarization Agility with Frequency Agility and Recognition.

An alternative to the four concepts discussed thus far in this report is considered promising enough that it is worthy of mention. It has been demonstrated that certain discrimination processing techniques when used with either polarization or frequency agility result in clutter suppression. The following paragraphs in this subsection will relate some of the background and will discuss the alternative configuration.

Georgia Tech investigations [2] with polarization agility have shown that the radar return from vegetation clutter tends to be more correlated on a pulse-to-pulse basis for a single polarization than it is correlated between orthogonal polarizations. Therefore, over several pulses, an amplitude modulation may be induced in the return from clutter by switching polarizations on alternate transmissions. By processing the return with circuitry which discriminates against such modulation, it was found that significant clutter suppression was achieved. Man made targets, due to the regularity and composition of their construction, provide much stronger correlation of one polarization as compared with the other. Obviously, if other techniques could cause similar modulation to be introduced in the clutter return, the same discrimination techniques would apply.

Thus experiments were conducted using frequency agility. The frequency agility caused the returns from clutter cells to decorrelate significantly on a pulse-to-pulse basis thereby creating the desired discriminant, amplitude modulation. The results were even better than those achieved using polarization agility. While the phase effects as well as the amplitude modulation were being investigated as a possible discriminant, a third concept was originated.

The third concept was generated as a result of a brief internal concept generation effort, related to a noise radar concept. This concept embodies both the polarization and wideband (or frequency agility) concepts in such a configuration that clutter discrimination, pulse compression, and correlation all seem possible. The concept also includes phase discrimination, rather than amplitude modulation discrimination, as the discriminating technique. The concept is called Intrapulse Polarization Agile Radar (IPAR) and has been communicated to MICOM. Figure 8 shows a radar configured for transmitting circular polarization and for receiving and phase detecting the two orthogonal components. By phase shifting one received component by 90° and phase detecting between the two components, the polarization scattering properties of manmade objects may be used as a discriminant to separate such objects from clutter. Since there are no restrictions within limits on the frequency or phase of the r-f energy in the transmit cycle before it is split into the two components, one is free to choose these parameters as he wishes.

Figure 9 shows how a code generator may be employed to cause the transmitted energy to be switched according to any arbitrary code, which in turn may be stored for reference during the receive cycle.

Comparison of the phase detected received signal with this reference provides the correlation in near real-time. Compression is achieved by

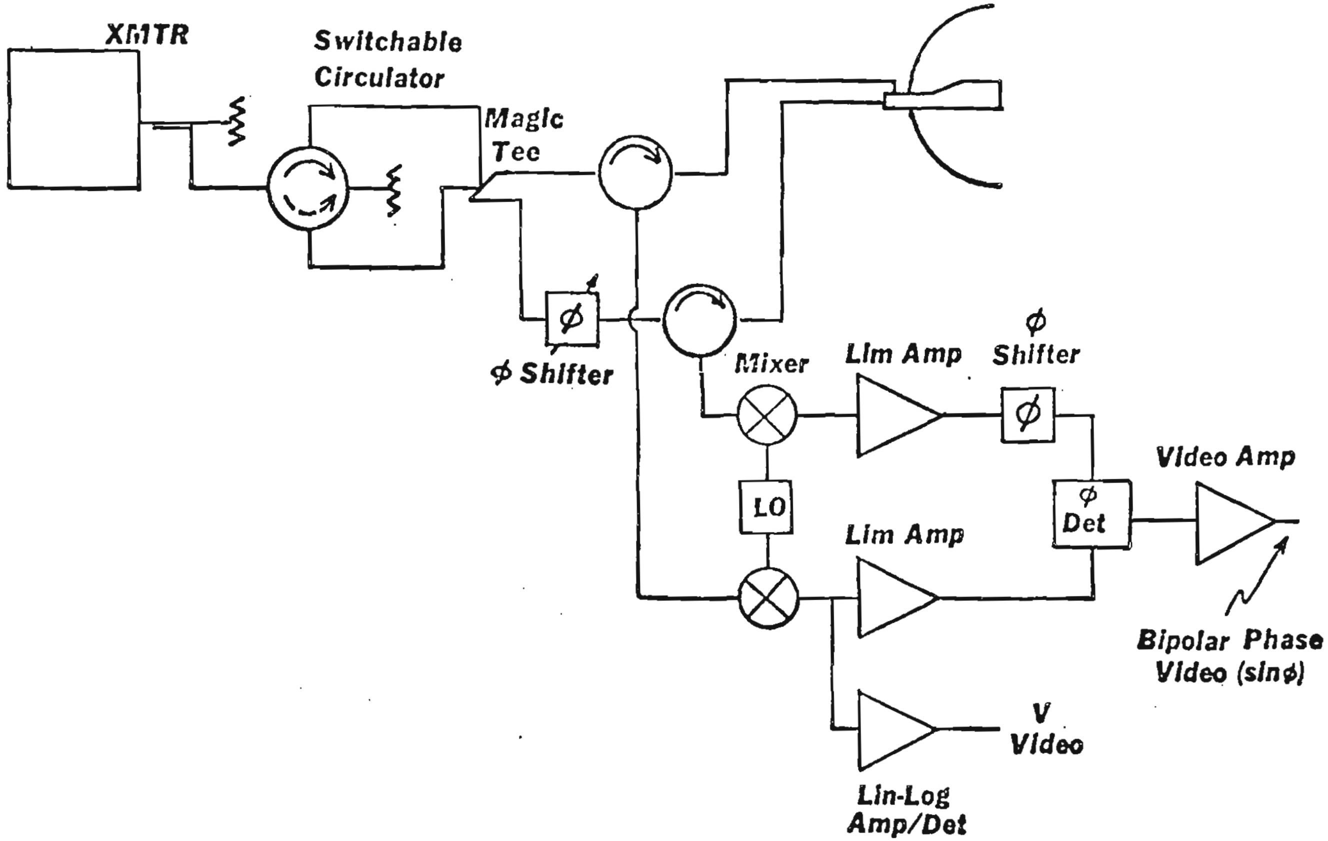


Figure 8. Circular Polarization Phase Detection Radar

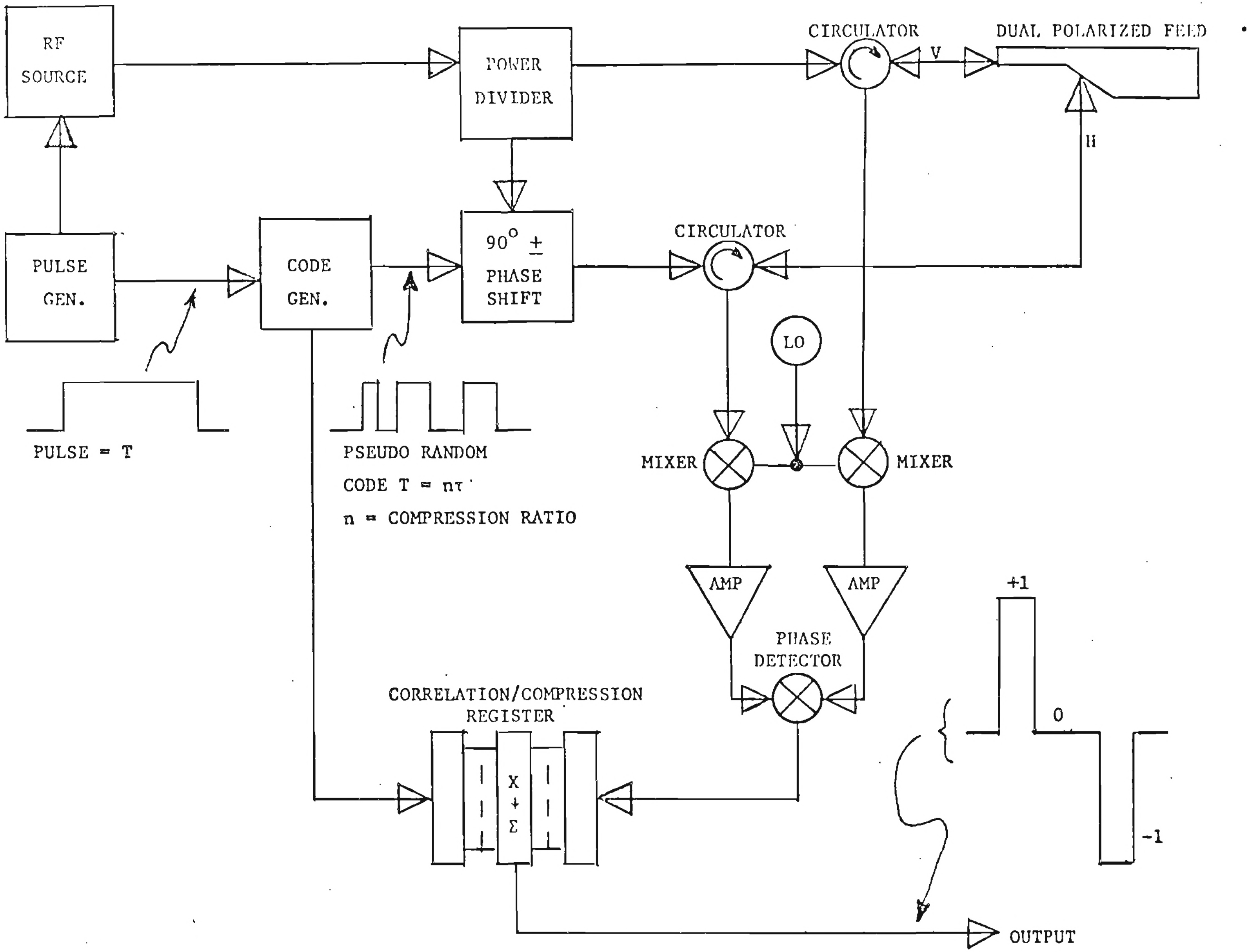


Figure 9. Simplified Block Diagram of IPAR Compression and Correlation System.

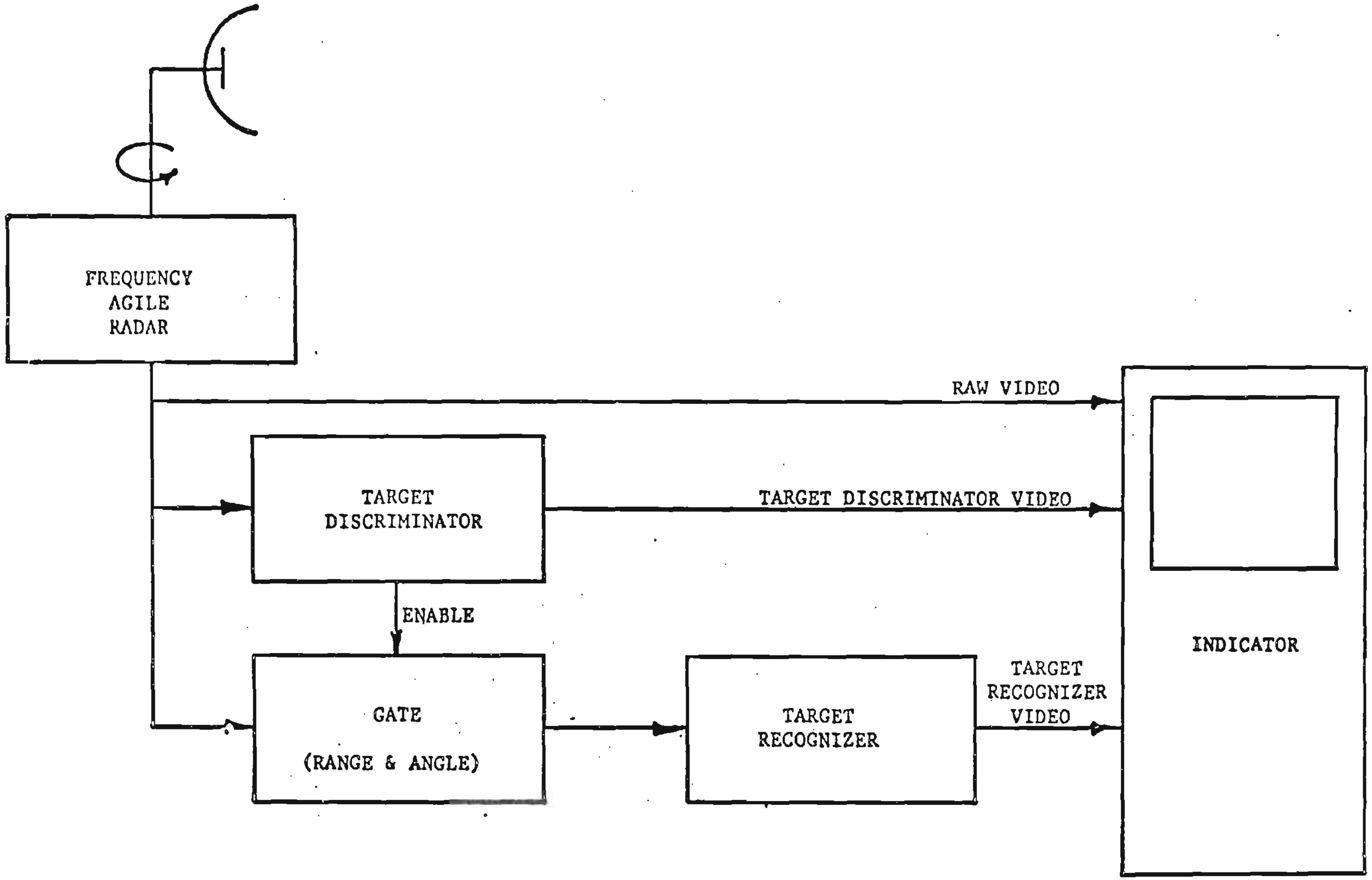


Figure 10. Target Discrimination and Recognition Concept

virtue of the fact that multiple subpulse switching is correlated over the entire pulse and summed during one switch time interval. The compression ratio is the ratio of the radar pulse width to the switching time interval for polarization coding.

This concept has several potential advantages including the following:

4.3.1 Correlation.

4.3.2 Target from clutter discrimination.

4.3.3 ECM advantages.

4.3.4 Pulse compression (means of achieving pseudo short pulse with attendant resolving ability).

The last potential advantage mentioned is interesting in that pseudo short pulse video may be useable in conjunction with or in lieu of normal video for range profile recognition. Also this concept embodies the polarization agile configuration which was used for Configuration 4 of this report as a subelement.

Figure 10 shows how this concept or other discrimination concepts might optimumly be used in conjunction with recognition concepts. This figure reflects the envisioned usage of the discrimination techniques to perform the necessary real-time discrimination and to designate manmade type objects to the recognizer for longer (many pulse periods) analysis and recognition attempts.

Preliminary analysis indicated that if the concept were to prove feasible and no unexpected technological barriers were met, up to 20 dB of clutter suppression may be achievable in nontarget cells and that detection of targets for target-to-clutter ratios of as little as 0 dB or less for in-cell clutter may be possible.

5. CONCLUSIONS AND RECOMMENDATIONS

Technical Requirement No. 1 required that the feasibility of polarization agility implemented with target recognition be determined. The technique which has been selected was determined as the result of a visit to Benedix by Georgia Tech personnel. The design analysis required for determining the feasibility was simplex. That the technique was feasible was demonstrated in the form of working hardware.

The technique for implementing polarization agility with recognition in the test configuration and in an envisioned operational configuration was discussed herein. No problems are foreseen in the envisioned operational configuration. The results achieved using the test configuration are not universally applicable to the envisioned operational configuration, however. The basic question that can be addressed in the test configuration and the result qualitatively extrapolated to an operational configuration is whether the employment of two separate recognition algorithms with two orthogonal polarizaions will yield better performance than a single algorithm and polarization.

5.1 Note that there are really four possible combinations of polarization/ hyperplane models to be examined. These are shown below:

5.1.1 Vertically polarized transmit and vertical receive with optimum recognition hyperplane model.

5.1.2 Vertically polarized transmit with cross polarized reception.

5.1.3 Horizontally polarized transmit with parallel reception.

5.1.4 Horizontally polarized transmit with cross polarized reception.

Four system configurations were defined in Section III. A Swerling Case I model for clutter and a nonfluctuating model for the target was assumed. These models apply in only a limited number of specific circumstances and then are only approximations. However, the uniform treatment of the four cases combined with deductive reasoning does lend credibility to the significance of the relative performances.

It is concluded that the performance of the polarization agile radar would not be very much better in discriminating targets from clutter than the simple radar. This assumes no special discrimination processing, of course. With discrimination processing, the case is quite different.

It is concluded that polarization agility used in conjunction with range profile recognition would provide better discrimination capability than the radar with recognition alone. This conclusion is more the result of subjective reasoning than it is of extensive mathematical analysis. If the two polarizations contributed equally to the discrimination processing, the target recognition with polarization agility configuration would provide $\sqrt{2}$, or 1.51 dB performance improvement over the recognition without polarization agility configuration. The mathematics merely reflected the reasoning that more independent looks reduce the probability of error in declaring the existence of a target.

5.2 No conclusive comparison could really be accomplished between the two configurations employing recognition and the two without recognition. The reason is that adequate data were unavailable for assessing the discrimination performance of the recognizer. Whenever such data are available it is recommended that the following three considerations be taken into account:

5.2.1 The difference between recognition and discrimination as defined herein.

5.2.2 Differentiating between required target to clutter signal level for the target cell and the total group of cells, within the required radar coverage area.

5.2.3 The resolution cell processing rate as compared with the frequency of false recognitions and operational requirements.

In view of the lack of available data, the only basis for comparing recognition systems with nonrecognition systems was that the recognition systems could always be viewed as containing the nonrecognition systems as subelements. With this logic, one can say that the best discriminating configuration of the four is the one consisting of radar with polarization agility and recognition.

Comparative words like good, better, and best have been used in this analysis. Though esthetically pleasing, in light of available data it would have been pretentious to have conducted a rigorous mathematical analysis.

Several other tasks, some conducted independently and some in conjunction with this contract, are discussed as they relate to the objective and intent of this contract. In an effort to envision an operational system which would be compatible with both recognition and discrimination concepts, several alternatives were discussed. Such compatibility considerations also resulted in a moderately detailed short pulse study. Several technical risk or problem areas in the use of very short pulses ($\tau \approx 1$ to 30 nsec) were identified. Sources and techniques for generating short pulses were identified. A short pulse radar was located which confirmed several problem areas and techniques. Finally an optimum pulse width was recommended ($\tau \simeq 30$ns).

The final section of the analysis suggested a potentially useful concept which embodies the concepts of correlation, compression, polarization agility, and discrimination. This hypothetical configuration also offers the potential flexibility to be used in conjunction with recognition equipment.

It is recommended that such concepts be investigated in an ordinary multi-phase process of concept generation; concept definition; analysis and experimentation; and, finally, if warranted, concept development.

It is also recommended that such concepts should be expanded in scope with greater emphasis being placed on the targeting, fire control, and operational aspects.

REFERENCES

1. Skolnik, M. I., Introduction to Radar Systems, New York: McGraw-Hill Book Company, 1962, p. 65.

2. Eaves, J. L., et. al., "Investigation of Target Enhancement Techniques," Contract F33615-71-C-1612, Georgia Tech Project A-1330, July 1972.

APPENDIX A

Signal-to-noise ratio calculations for various Swerling fluxuation cases.

Case 1.

$$\frac{S/N}{E_i} = \frac{2}{3}\left(1 + \frac{2}{3}\, e^{\frac{-E_i N}{3}}\right) \frac{\log \frac{.693}{P_{fa}}}{\log \frac{1}{P_d}}$$

S/N = Required signal to noise ratio

E_i = Pulse integration efficiency

N = Number of pulses integrated

P_{fa} = Probability of false alarm due to noise

REQUIRED S/N FOR DETECTION OF CLUTTER WITH INDICATED P_d

P_{fa}	P_d	E_i	N	$\frac{S/N}{E_i}$	(dB)
0.1	0.1	0.5	20	0.12	-9.08
10^{-6}	0.1	0.5	20	0.86	-0.66
10^{-6}	10^{-6}	0.5	20	0.14	-8.44
10^{-6}	0.95	0.5	20	38.55	15.86

Case 5.

$$\frac{S/N}{E_i} = \frac{1 + 2e^{\frac{-E_i N}{3}}}{(E_i N)^{\frac{2}{3}}} \; \frac{\log \frac{.693}{P_{fa}}}{\left(\log \frac{1}{P_d}\right)^{\frac{1}{6}}}$$

REQUIRED S/N FOR 95% TARGET DETECTION

P_{fa}	P_d	E_i	N	$\frac{S/N}{E_i}$	(dB)
10^{-6}	.95	0.5	20	2.54	4.05
0.1	.95	0.5	20	0.37	-4.37

For

$$P_{fa} = 0.1$$

$$P_{d|clutter} = 0.1 \text{ Swer } 1$$

$$P_{d|target} = 0.95$$

$$\frac{S_T}{S_c} = \frac{0.37}{0.12} = 3.05 \simeq 4.84 \text{ dB}$$

For

$$P_{fa} = 10^{-6}$$

$$P_{d|clutter} = 0.1 \text{ Swer } 1$$

$$P_{d|target} = 0.95$$

$$\frac{S_T}{S_c} = \frac{2.54}{0.86} = 2.95 \simeq 4.70 \text{ dB}$$

(Apriori Target-to-Clutter ratio simple radar)

For

$$P_{fa} = 10^{-6}$$

$$P_{d|clutter} = 10^{-6}$$

$$P_{d|target} = 0.95$$

$$\frac{S_T}{S_c} = \frac{2.54}{.14} = 18.4 \simeq 12.59 \text{ dB}$$

(Multicell Target-to-Clutter ratio for simple radar)

Signal-to-Noise ratio calculations of radar with polarization agility.

The required $\frac{S/N/C}{E_i}$ for 0.1 P_d for clutter is 0.86 per pulse for N pulses with an integration efficiency of E_i. If we assume equal contributions to the composite $\frac{S/N}{E_i}\Big|_{clutter}$, then

$$\frac{\frac{S}{N}}{E_i}\Bigg|_{clutter} = \left[\left(\frac{1}{2}\frac{S}{N}\Big|cv\right)^2 + \left(\frac{1}{2}\frac{S}{N}\Big|ch\right)^2\right]^{\frac{1}{2}}$$

$$\frac{S}{N}\Big|cv = \frac{S}{N}\Big|ch$$

$$\frac{S}{N}\Big|\text{ clutter} = \left[\frac{1}{2}\frac{S}{N}^2\right]^{\frac{1}{2}} = \frac{\frac{S}{N}\big|cv}{\sqrt{2}}$$

or

$$\frac{S}{N}\Big|_{cv} = \sqrt{2}\ \frac{S}{N}\Big|clutter$$

$$\frac{\frac{S}{N}\big|cv}{F_{-i}} = \sqrt{2}\ \frac{\frac{S}{N}\big|clutter}{E_i} \cong 1.22 \text{ or } 0.8 \text{ dB}$$

For the target with $P_d = 0.95$ and $P_{fa} = 10^{-6}$

$$\frac{S}{N}\Big|Tgt = \frac{1}{2}\frac{S}{N}\Big|_{TV} + \frac{1}{2}\frac{S}{N}\Big|_{TH}$$

$$\frac{S}{N}\Big|_{TV} = \frac{S}{N}\Big|_{TH}$$

$$\frac{S}{N}\Big|_{Tgt} = \frac{S}{N}\Big|_{TV}$$

$$\frac{\frac{S}{N}\big|_{TV}}{E_i} = 1 \times 2.54 = 2.54 \text{ or } 4.05 \text{ dB}$$

Single cell target/clutter ratio required

$$\frac{\left.\frac{S}{N}\right|_{TV}}{\left.\frac{S}{N}\right|_{CV}} = \frac{2.54}{1.22} \cong 2.08 = 3.19 \text{ dB}$$

Apriori Single Cell Target-to-Clutter Ratio for Polarization Agility Radar

For Clutter at $P_d = 10^{-6}$

$$\frac{\left.\frac{S}{N}\right|_{CV}}{E_i} = \sqrt{2} \times 0.14$$

Total target/clutter ratio required $= \frac{2.54}{\sqrt{2} \times .14} = 12.83$ or 11.08dB

Multicell Target-to-Clutter Ratio for Polarization Agile Radar